

An Architecture that Facilitates the Development of Consensus on Strategies and Programs to Reduce Carbon Intensity

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GOAL OF THIS TALK

To make the case that we already have the tools to "solve" the global problem for the next half century.

To facilitate this argument by introducing a new physical unit, the **wedge**, as a useful unit for describing 50-year strategies.

To explain why the global carbon problem for the next 50 years is, roughly, a **seven-wedge problem**.

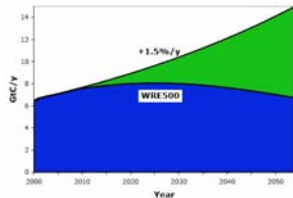
For several 50-year strategies that involve **already commercialized technologies**, to work out **how much action equals one wedge**.

To conclude that an excuse for inaction based on the world's lack of technological readiness does not exist.

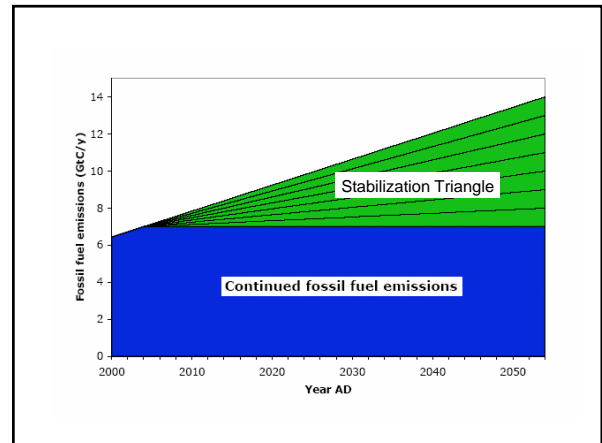
From Multiple Targets and Baselines to the Stabilization Triangle in Three Steps

Step One: Restrict attention to 50 years (the Goldilocks time frame)

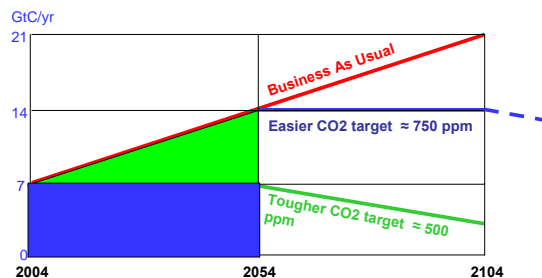
Step Two: Choose just one goal and one baseline



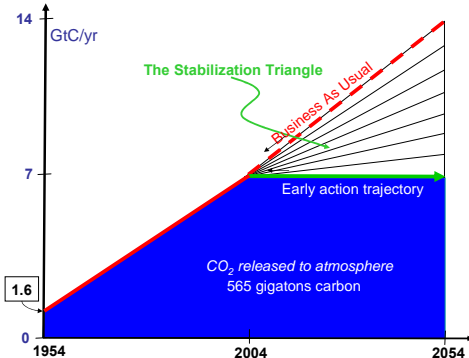
Step Three: Use only straight lines! Take the goal to be flat emissions and the baseline to be doubling linearly in 50 years.



The Stabilization Triangle: Looking Forward

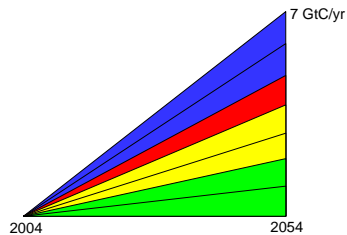


The Stabilization Triangle: Looking Back



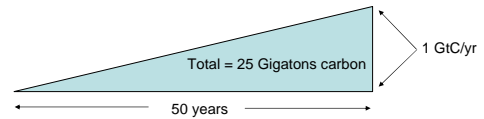
Seven "Wedges" Fills the Triangle

It is irresistible to divide the triangle into seven equal parts. We call these "wedges."



What is a "wedge"?

A "wedge" is an activity reducing the rate of carbon build-up in the atmosphere that grows in 50 years from zero to 1.0 Gt(C)/yr.



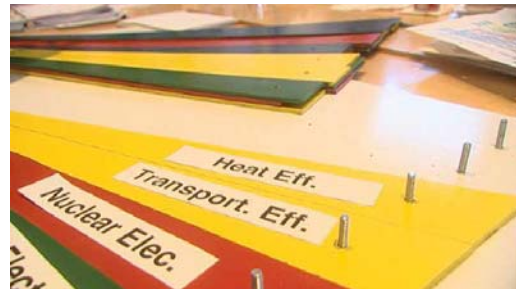
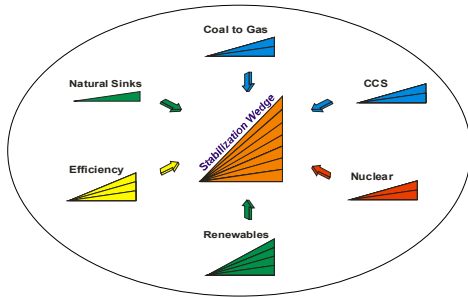
Cumulatively, a wedge redirects the flow of 25 Gt(C) in its first 50 years. This is 2.5 trillion dollars at \$100/t(C).

A "solution" to the Greenhouse problem should have the potential to provide at least one wedge.



Filling the Stabilization Triangle

Many candidate wedges are available that use proven technologies. We can start now.



Wedge Issues

- Business as Usual:

Stay focused on comparing two "stories":

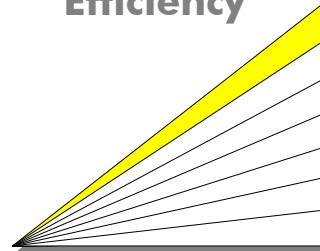
1. the world is oblivious to carbon management (BAU)
2. the world is investing heavily in carbon management

- Double counting

One can displace the emissions of a coal-based power plant only once!

Candidates for wedges, below, are assumed to be providing the *first* reduction in carbon emissions, i.e., from 14 GtC/y to 13 GtC/y.

Efficiency



1. Efficiency in transport



Effort needed for 1 wedge:
2 billion gasoline and diesel cars (10,000 miles/car-yr) at 60 mpg instead of 30 mpg

500 million cars now.

Potential Pitfall:

Suburban sprawl

2. Efficiency upstream

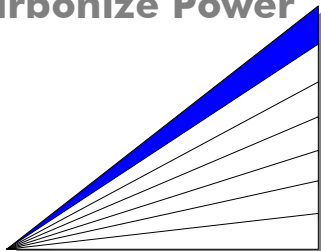
Effort needed for 1 wedge:

In 2054, "overheads" are 1 GtC/y, not 2 GtC/y, on fuels extraction, processing (tarsands), distribution (LNG) – upstream of power plants

By 2054, power plant efficiency is 60%, not 30%, on coal capacity equal to current coal capacity



Decarbonize Power



3. Coal to Gas for Electricity

Effort needed for 1 wedge:

By 2054, build 1400 GW baseload fueled by gas, not coal.
4 x current natural gas power output.

50 large LNG tanker discharges/day

Build one new "Alaska" pipeline/year



Cross-section of the GE MS9001H Advanced Gas Turbine Photo courtesy of DOE

Natural gas: 1 GtC/y = 190 Bscfd

Potential Pitfalls:

Natural gas geopolitics



4a. Carbon Capture



The Wabash River
Coal Gasification Repowering Project
Graphics courtesy of DOE Office of Fossil Energy

Effort needed for 1 wedge:

By 2054, CCS at 800 GW coal
or 1600 GW natural gas

Potential Pitfalls:

Second step, carbon storage, founders.

4b. Carbon storage



Graphic courtesy of Statoil ASA

Effort needed for 1 wedge:

By 2054, 3500 Sleipners

100 x current U.S. CO₂ injection for
enhanced oil recovery (EOR)

A volumetric flow of supercritical CO₂
greater than the flow of oil today

Potential Pitfalls:

Public acceptance
Global and local CO₂ leakage



5. Nuclear Electricity

Effort needed for 1 wedge:

By 2054, add 700 GW that
displaces coal

2 x current capacity



Graphic courtesy of NRC

Potential Pitfalls:

Nuclear proliferation and terrorism
Nuclear waste, NIMBY

6. Wind Electricity



Prototype of 80 m tall Nordex 2.5 MW wind
turbine located in Grevenbroich, Germany
(Danish Wind Industry Association)

Effort needed for 1 wedge:

By 2054, install 2,000,000 1-MW_p
windmills

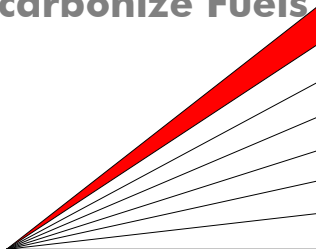
40,000 MW_p in place today,
growing 30%/yr

100 million hectares (10% of U.S.).
(Windmills are widely spaced,
compatible with multiple use.)

Potential Pitfalls:

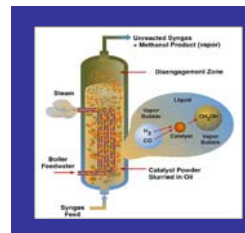
NIMBY
Changes in regional climate?

Decarbonize Fuels



7. Coal to Synfuels with CCS*

*Carbon capture and storage



Graphics courtesy of DOE Office of Fossil Energy

Effort needed for 1 wedge

By 2054, capture and store the CO₂ at
24 mbd synfuels plants

180 x Sasol, South Africa

assumes half of carbon originally
in coal can be captured

Potential Pitfalls:

Synfuel production proceeds,
but CCS is thwarted.

Oil: 1 GtC/y = 23.56 million barrels per day (mbd)

8. Fossil Fuel-based CCS* H₂

*Carbon capture and storage

Effort needed for 1 wedge:

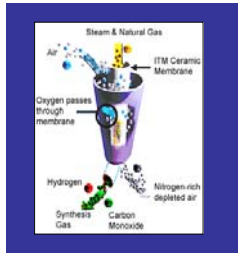
By 2054, 200 MtH₂/y (5x current) provide fuel for two billion very efficient fuel cell cars

If H₂ is from coal, as much coal for this wedge as for the CCS coal-to-power wedge

Potential Pitfalls:

Public acceptance of CO₂ storage

H₂-infrastructure, H₂ safety



Graphics courtesy of DOE Office of Fossil Energy

The U.S. DOE's FutureGen is a demonstration of this concept.

9. Biofuels

Effort needed for 1 wedge:

By 2054, 35 mbd ethanol fuel

150 x U.S. corn ethanol or Brazil sugarcane ethanol

Ethanol grown on 250 million hectares (one-sixth of all cropland)

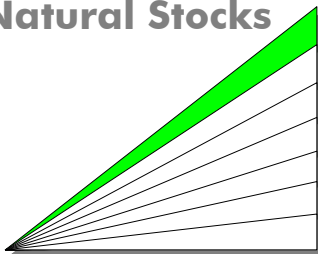


Photos courtesy of NREL

Potential Pitfalls:

Competing land use, biodiversity

Natural Stocks



10. Biological Stocks

Effort needed for 1 wedge:

By 2054, reduce current tropical deforestation by 100% instead of 50%

AND

Rehabilitate 400 million hectares (Mha) temperate OR 250 Mha tropical forest



Photo courtesy of NREL, SUNY Stonybrook

Potential Pitfalls:

Reversibility, verification

Effort needed for 1 wedge:

By 2054, conservation tillage on *all* cropland soils (15x current)

What's appealing about wedges?

The stabilization triangle:

- Does not concede doubling is inevitable.
- Decomposes a heroic challenge into a limited set of monumental tasks
- Shortens the time frame to within business horizons.

The wedge:

- Establishes a unit of action that permits quantitative discussion of cost, pace, risk.
- Establishes a unit of action that facilitates quantitative comparisons and trade-offs

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